Design Challenges of Digital Radiator Technology for Future NASA Space Missions

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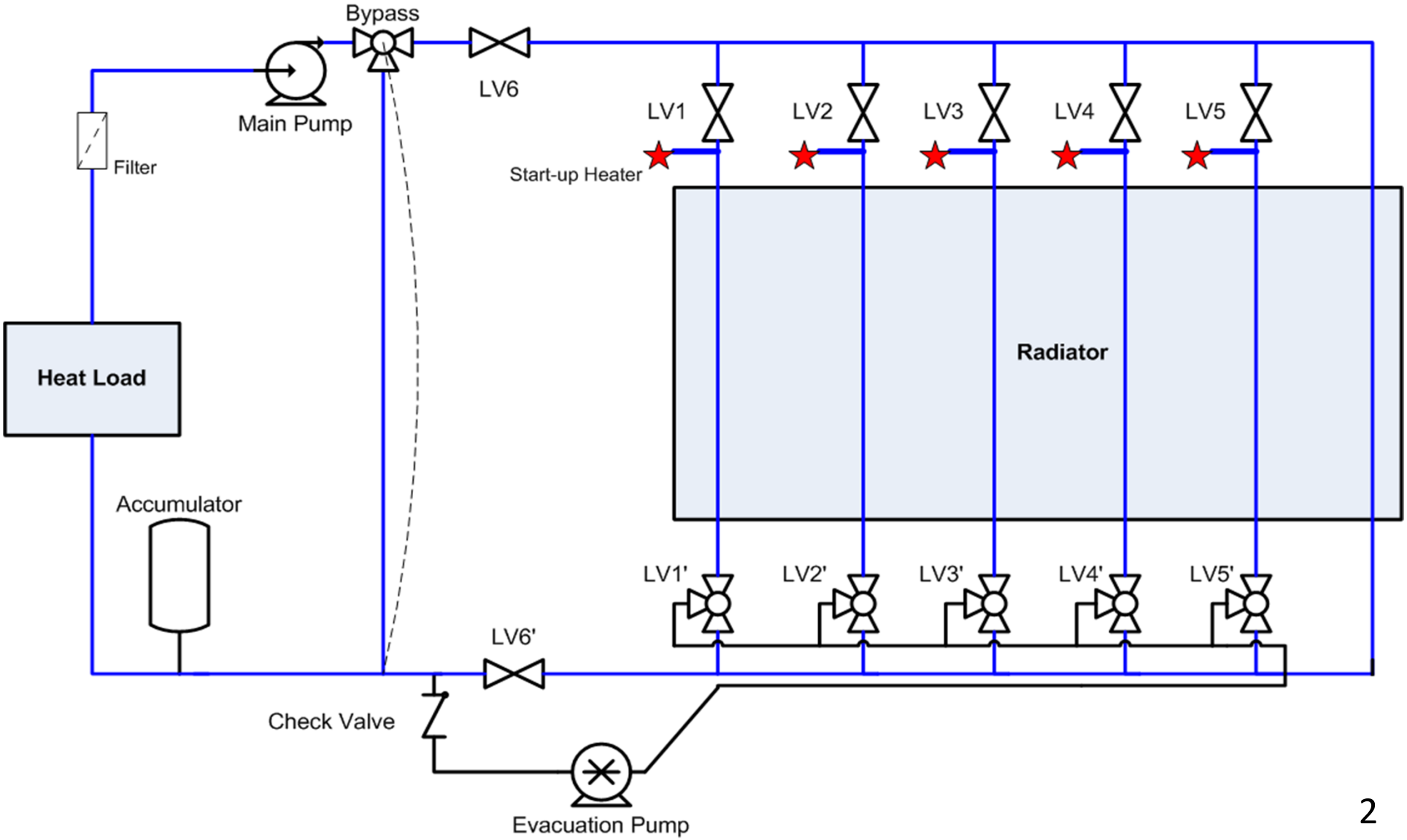
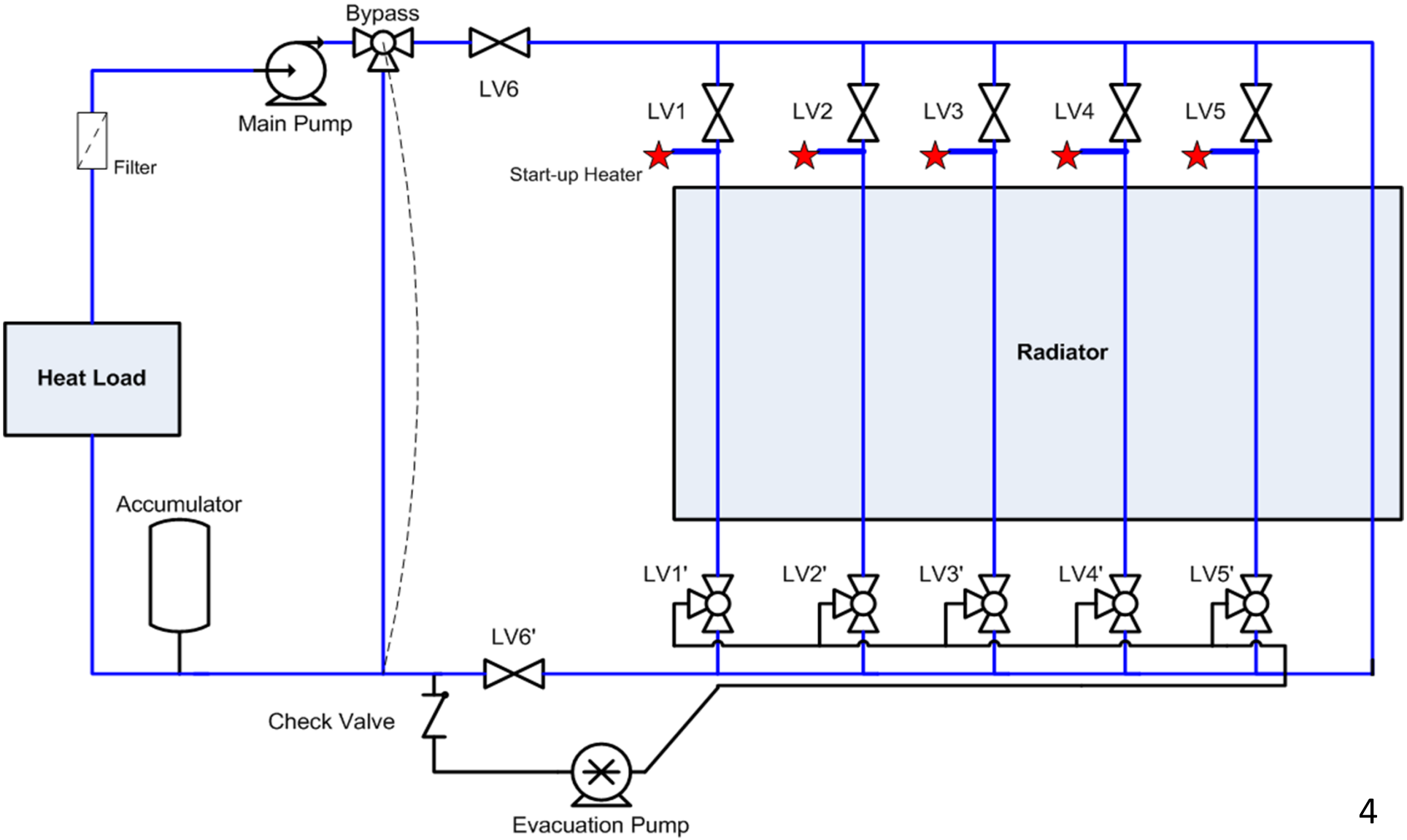
Digital Radiator Basic Design



Challenges

- Stopping flow in a leg
  - Fluid freezing
    - Fluid evacuation
      - Restarting flow

Stopping Flow in a “Leg”



Fluid “Freezing”

• PPG/ H2O	-30°C	(baseline)
• Therminol D-12	-100°C	
• MultiTherm ULT-170	-129°C	
• MultiTherm WB-58	-62°C	
• Novec 7200	-138°C	
• Galden HT-170	-97°C	
• QTherm SZ2	-50°C	

Freeze Experiment Setup

Lexan containment box for GN2 purge

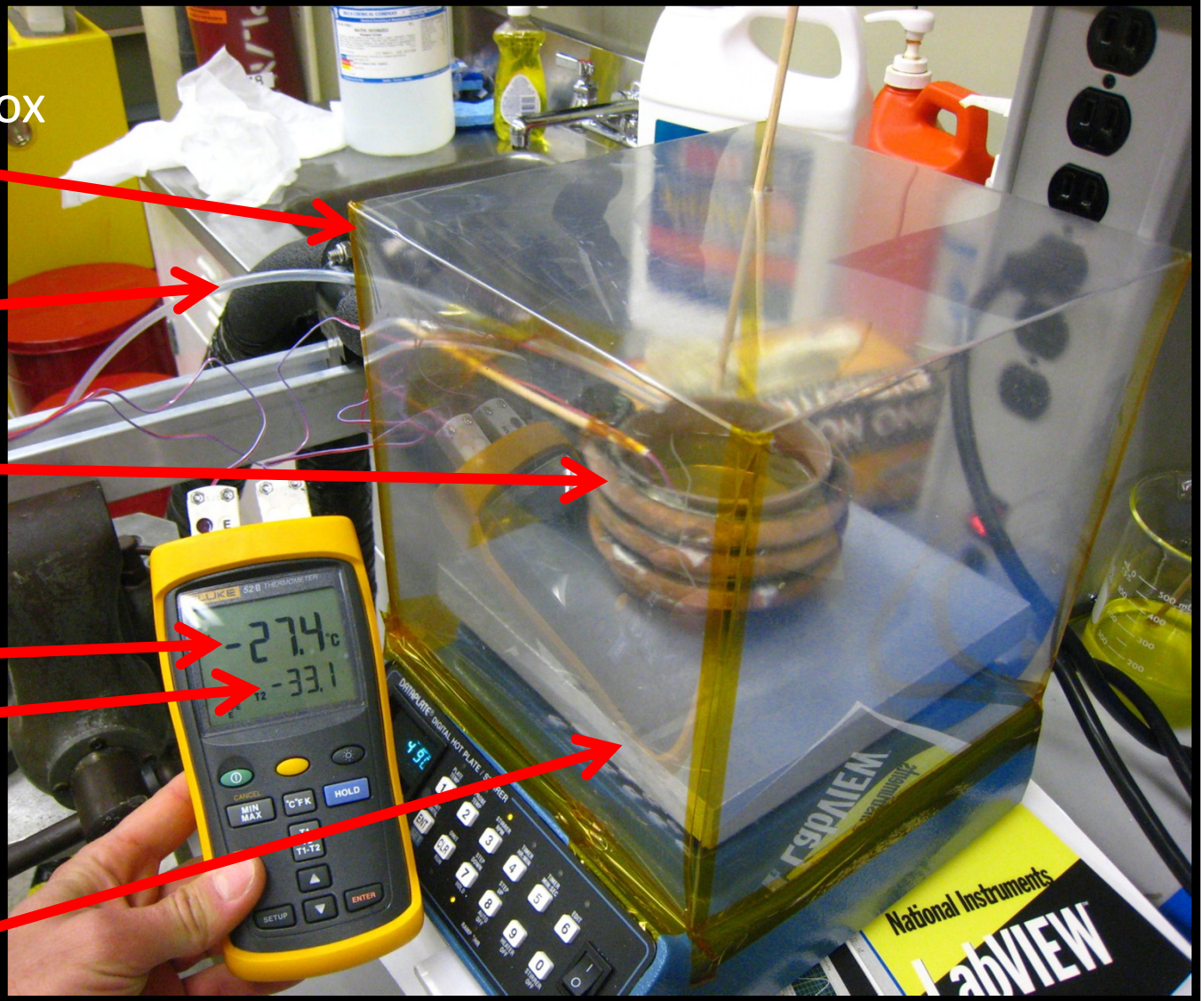
GN2 purge line

Heat x-changer cup

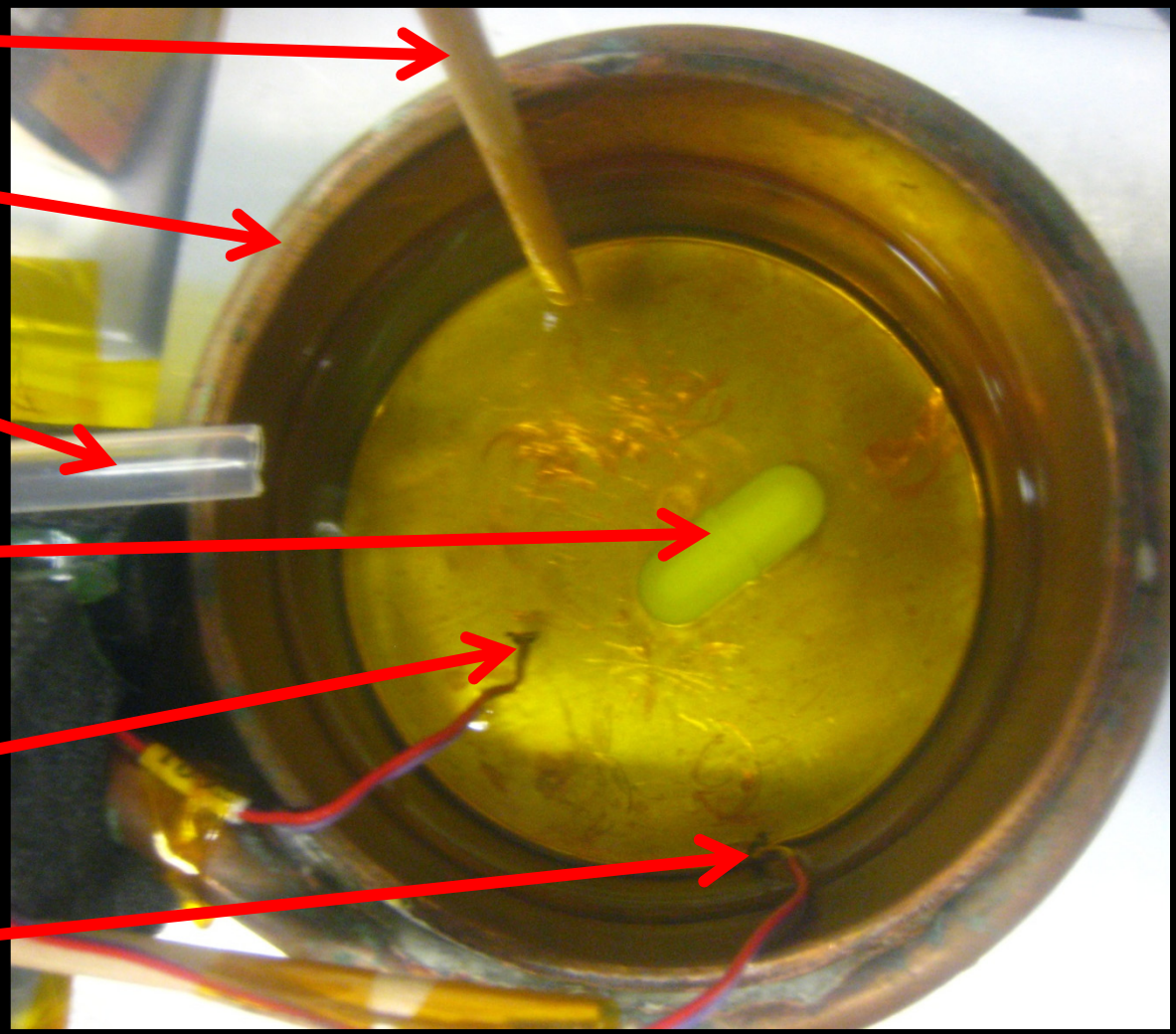
Bulk fluid T

Inside wall T
(replaced by datalogger)

Mag. Stir plate

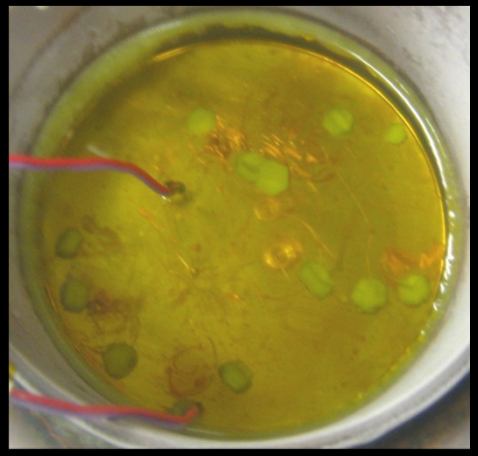


Freeze Experiment Setup (top view)

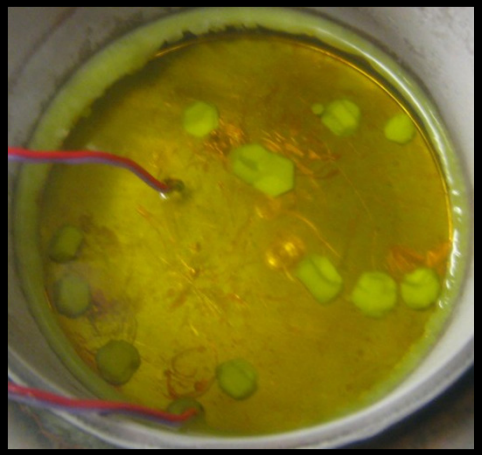


Unstirred freeze test (50 min bet 1st and last frame)

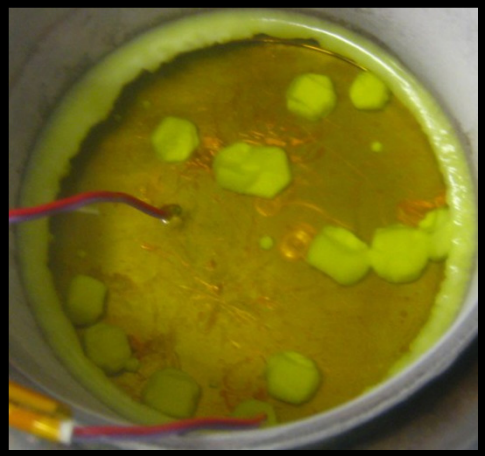
Bulk T: -34C
Wall T: -39C



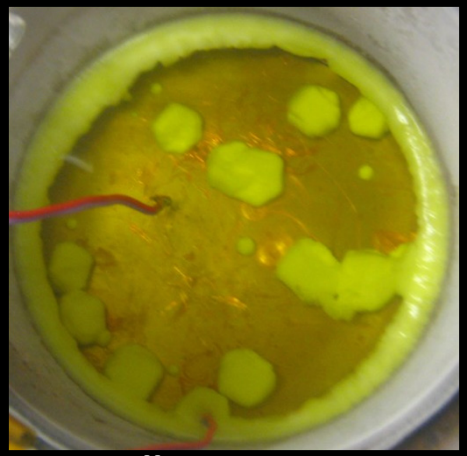
Bulk T: -36C
Wall T: -44C



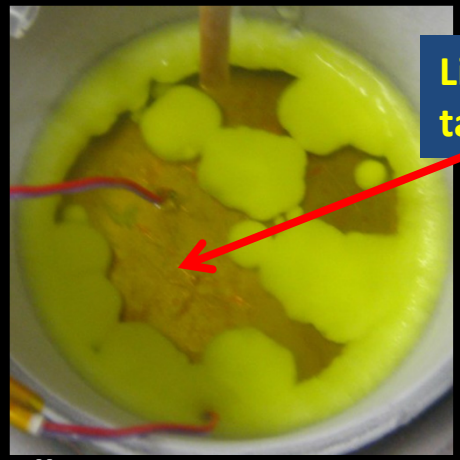
Bulk T: -37C
Wall T: -46C



Bulk T: -38C
Wall T: -48C



Bulk T: -38C
Wall T: -50C



Bulk T: -38C
Wall T: -50C (min attainable T - extra 20 min)

Concentration analysis

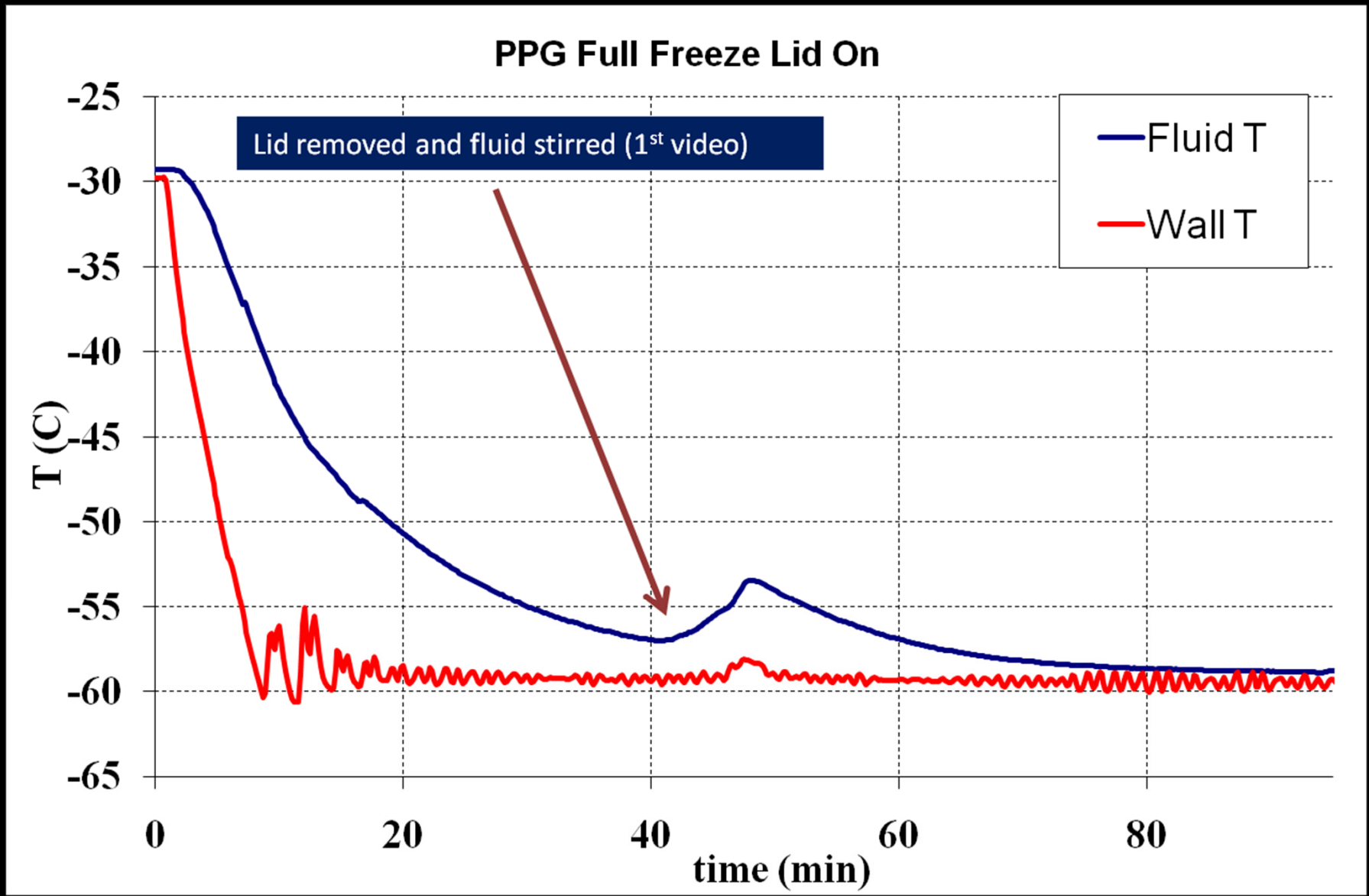
- PPG percentage measured in sample of unfrozen liquid
- Results show little concentration change

Freeze video

- In this video, the liquid begins at bulk T=-29C. At the start of the video, the chiller is set to -38C, which drops the wall T to -35C. Final bulk T = -35C
- The post-freeze clip at the end is after 40 minutes of unstirred freezing. Bulk T=-57C

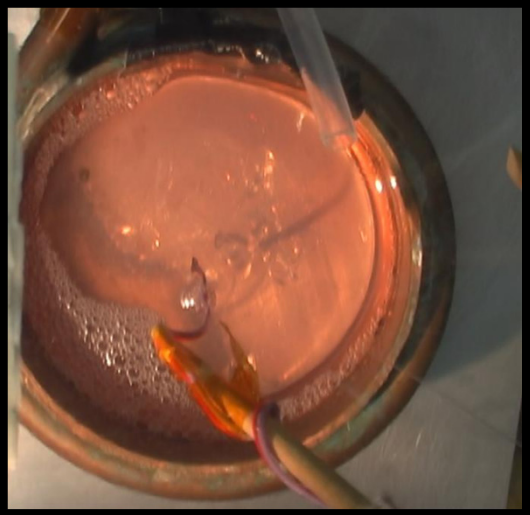
Video: PPG_freeze_captioned_cut.wmv

Thermocouple data from unstirred test

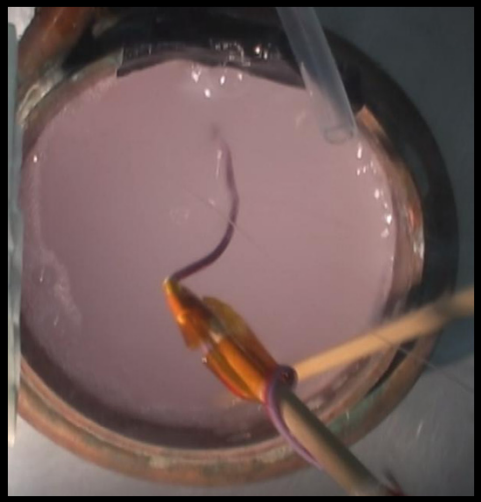


Qtherm freeze test

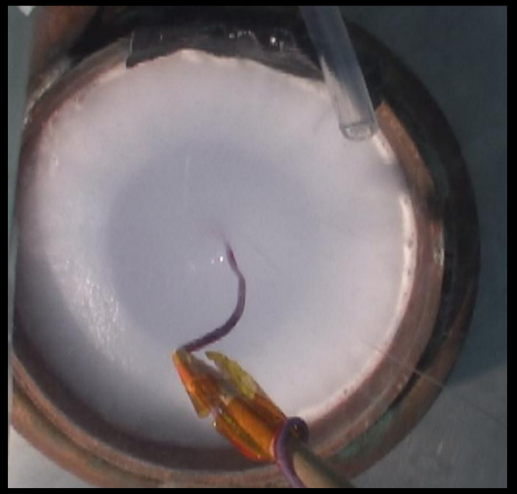
(Temp at center, 70 min. time)



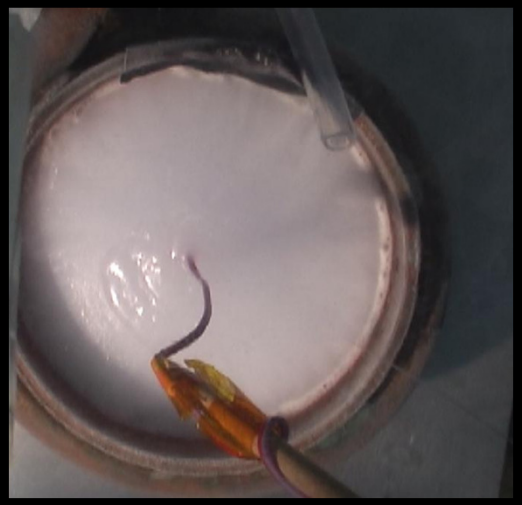
Initial State > 0 C



Cooling -5 C



Freezing -26 C

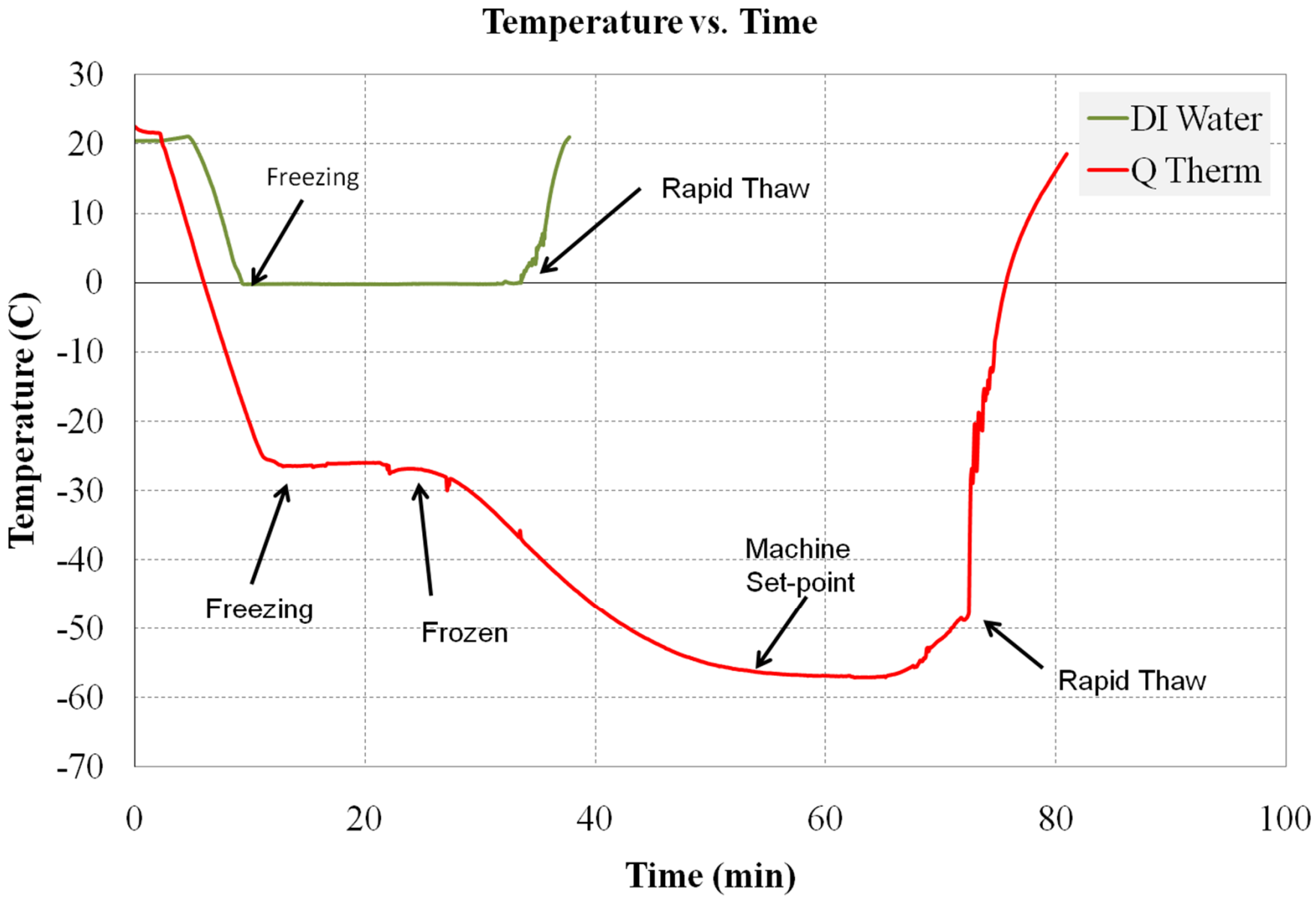


Frozen -30 C

(Hand stir) Broken up -30 C

Thawing -10 C

Qtherm TC data unstirred



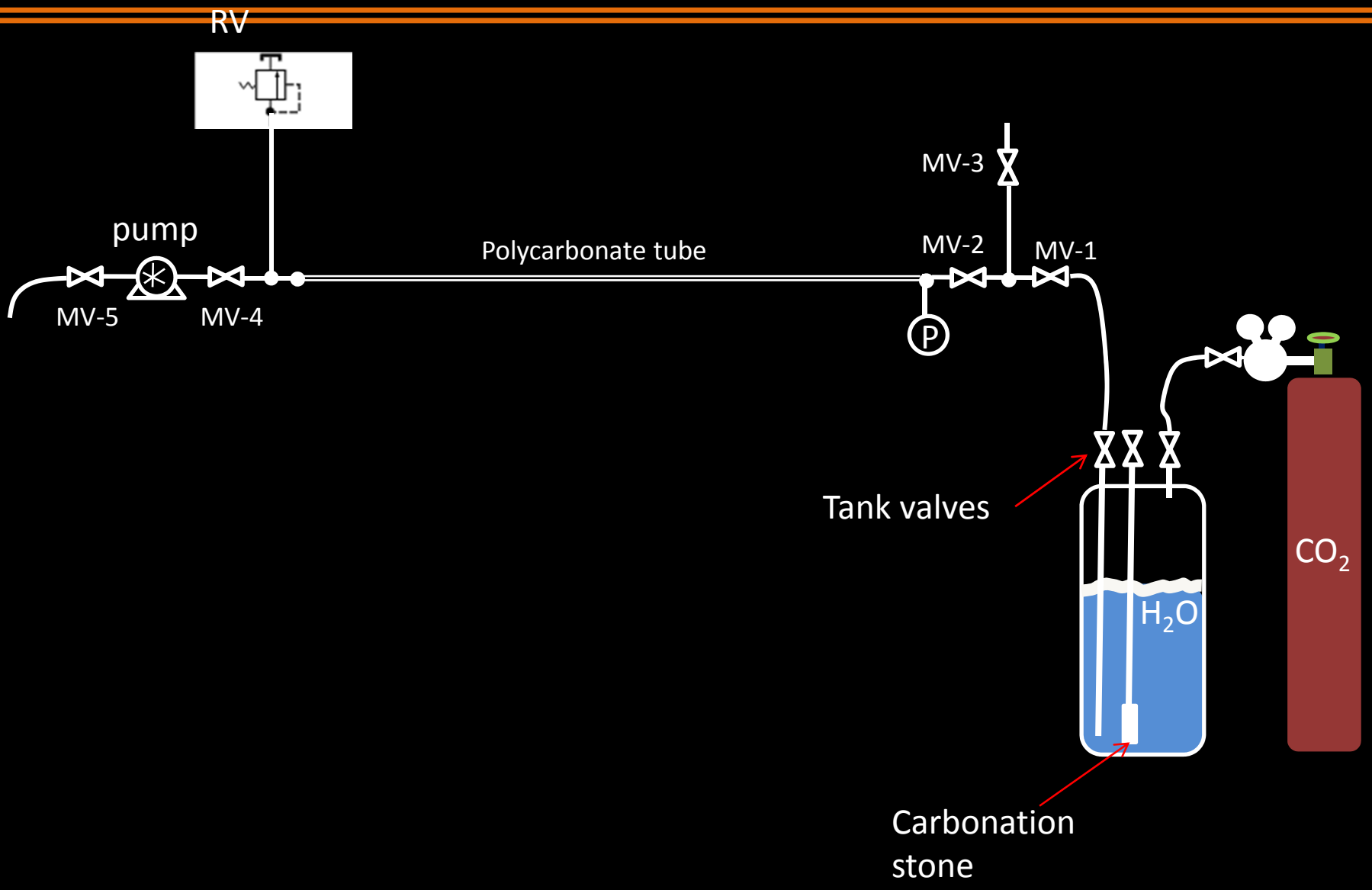
Lessons Learned from Freeze Tests

- Freezing behavior not well characterized
- Difficult to predict flow-stopping T
- Must fully evacuate fluid from stopped legs

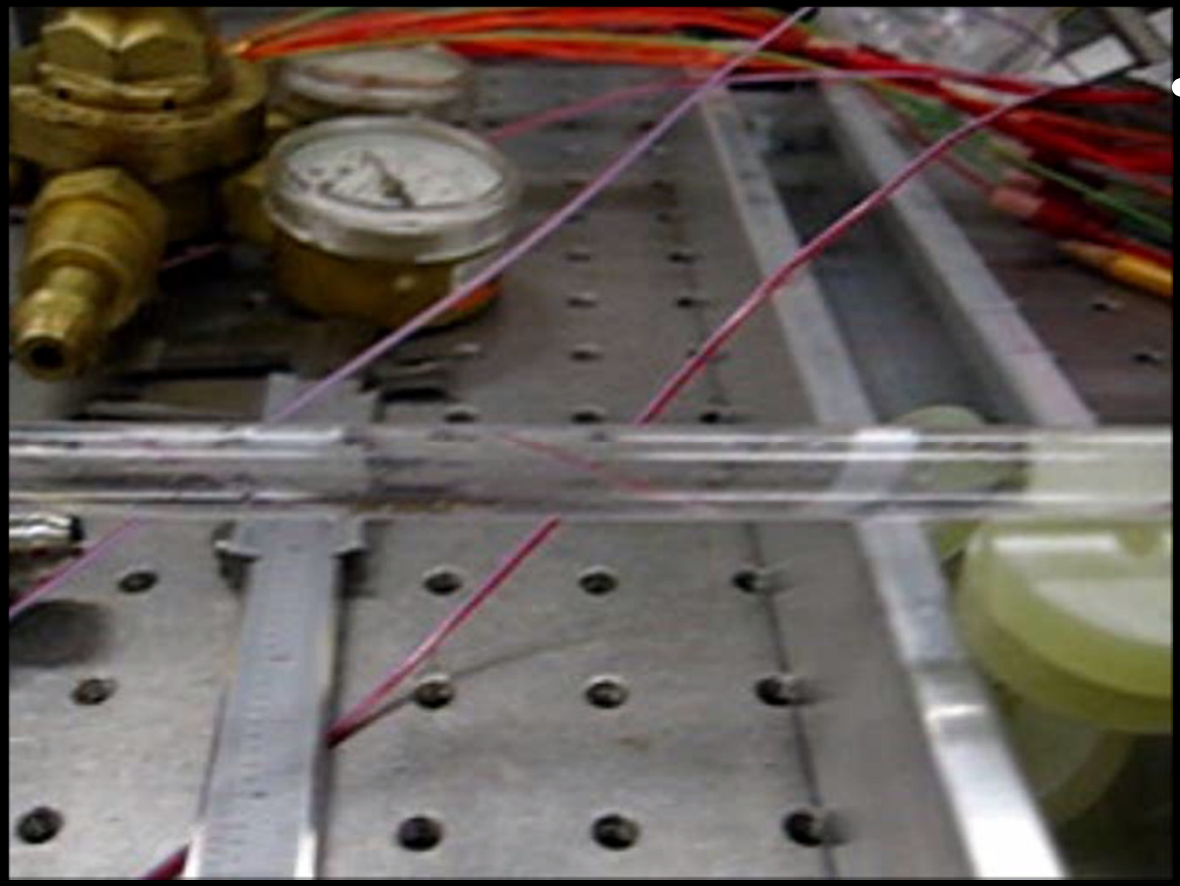
Fluid Evacuation Experiments

- Test of different evacuation techniques
  - Vacuum pump
  - Vent to space
  - Dissolved CO_2
  - Bubble Injection
  - Heater/ pump

Dissolved CO_2 Experiment



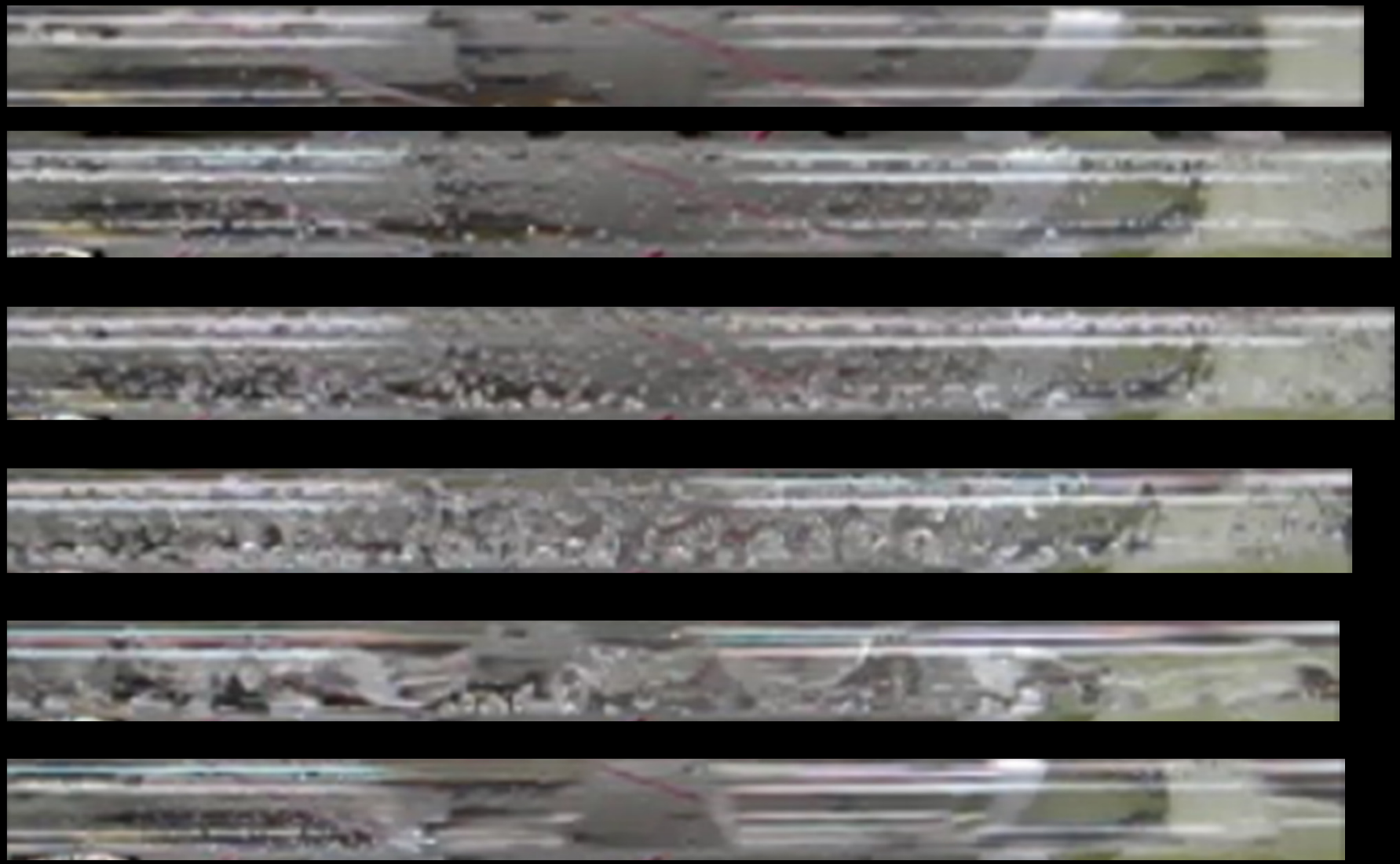
Dissolved CO_2 Experiment



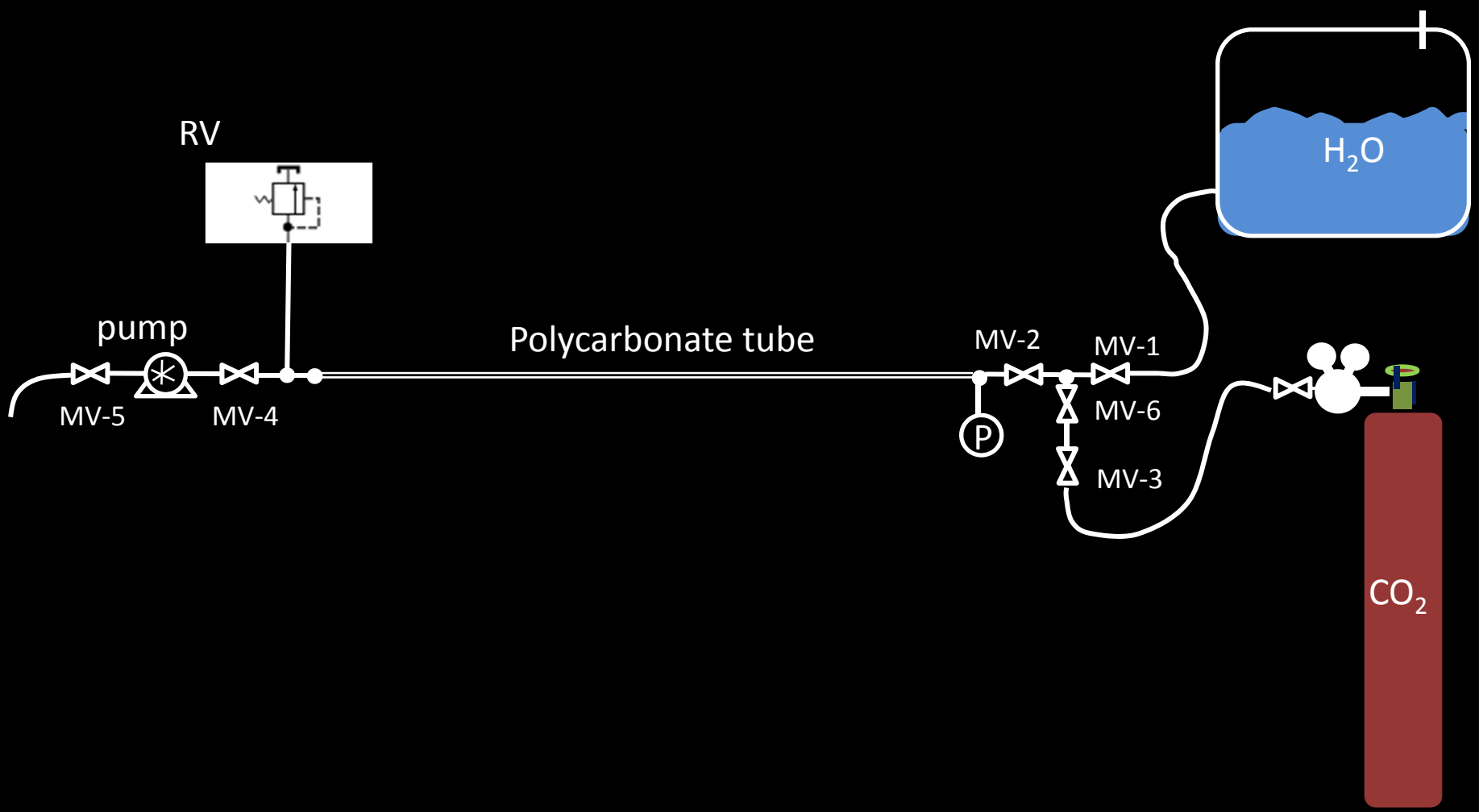
- Fails to evacuate due to uniform bubble forming all over tube

Video: carbonation_video_cut.wmv

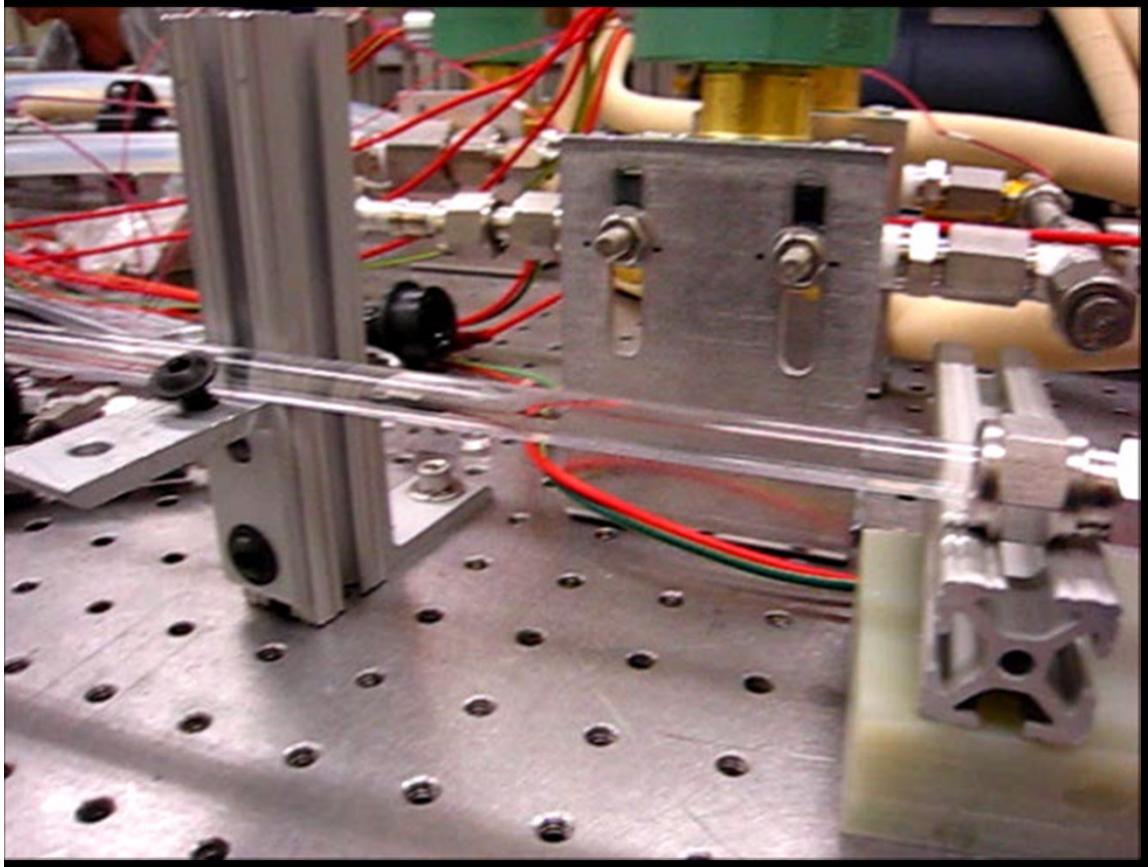
Dissolved CO_2 Experiment



Bubble Injection Experiment



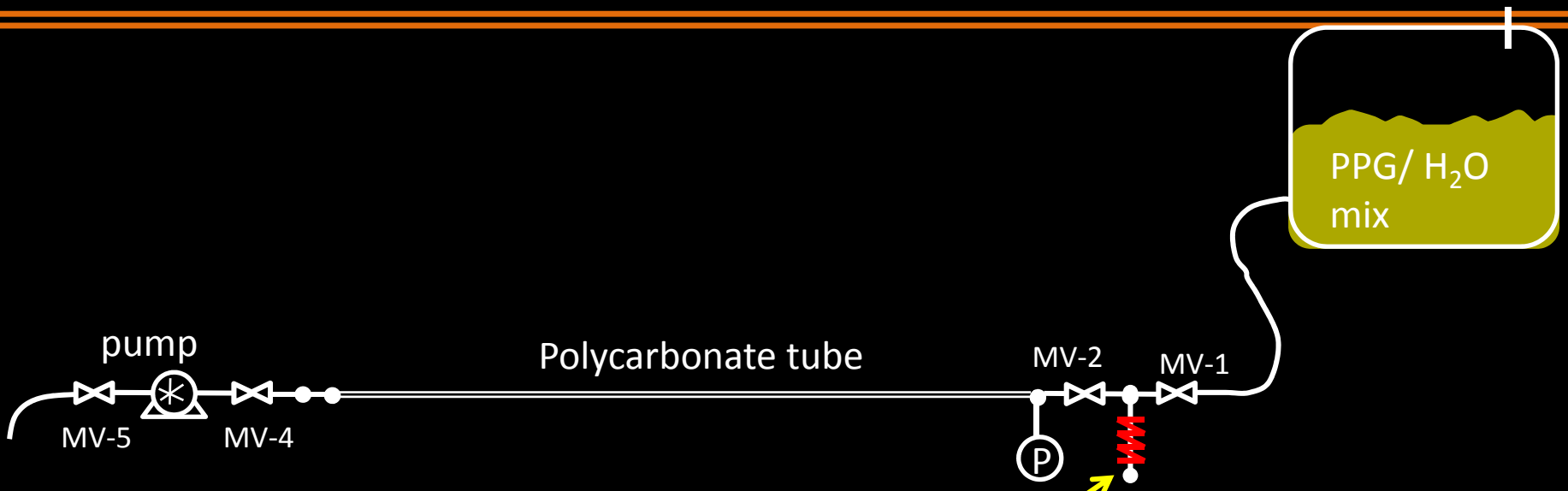
Bubble Injection Experiment



- Evacuates well
- Added complexity to S/C to remove gas

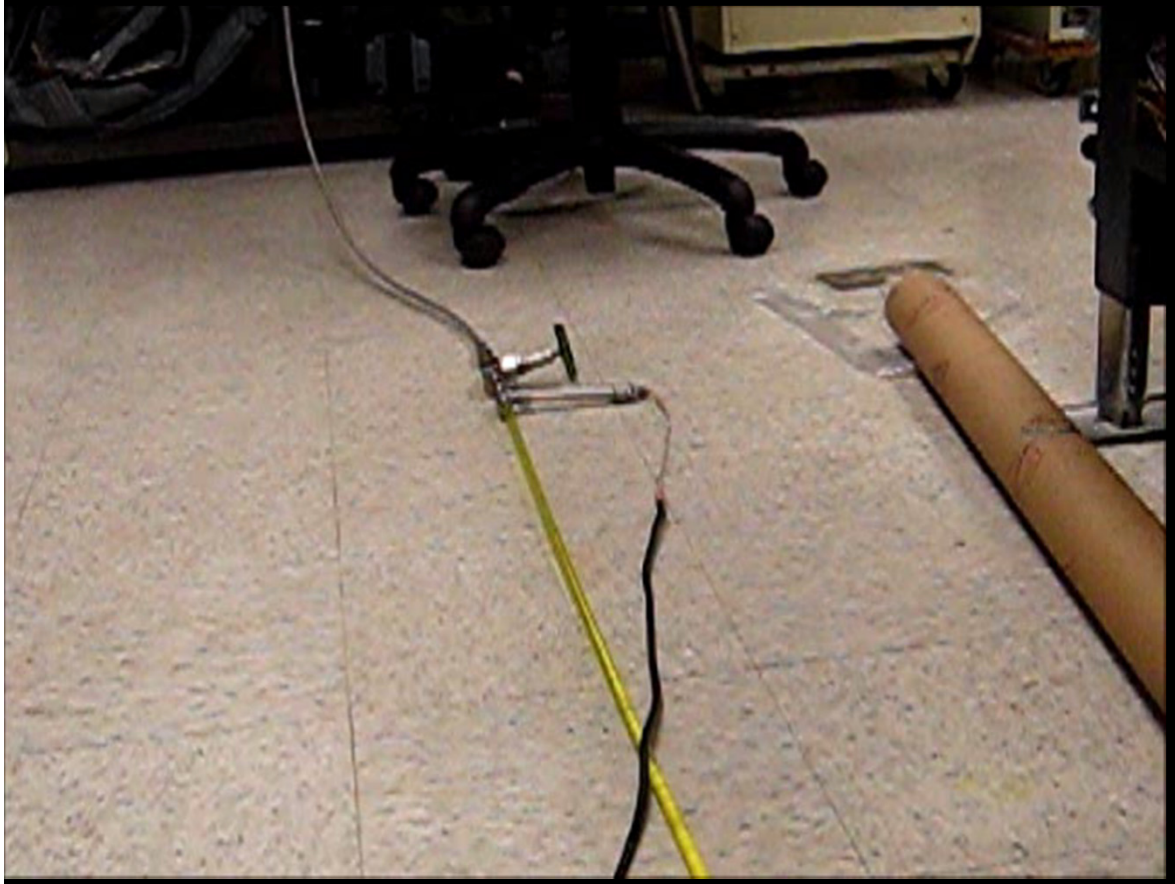
Video: bubble_injection_video_cut.wmv

Startup Heater Experiment



Immersion heater in "stub" leg

Startup Heater Experiment

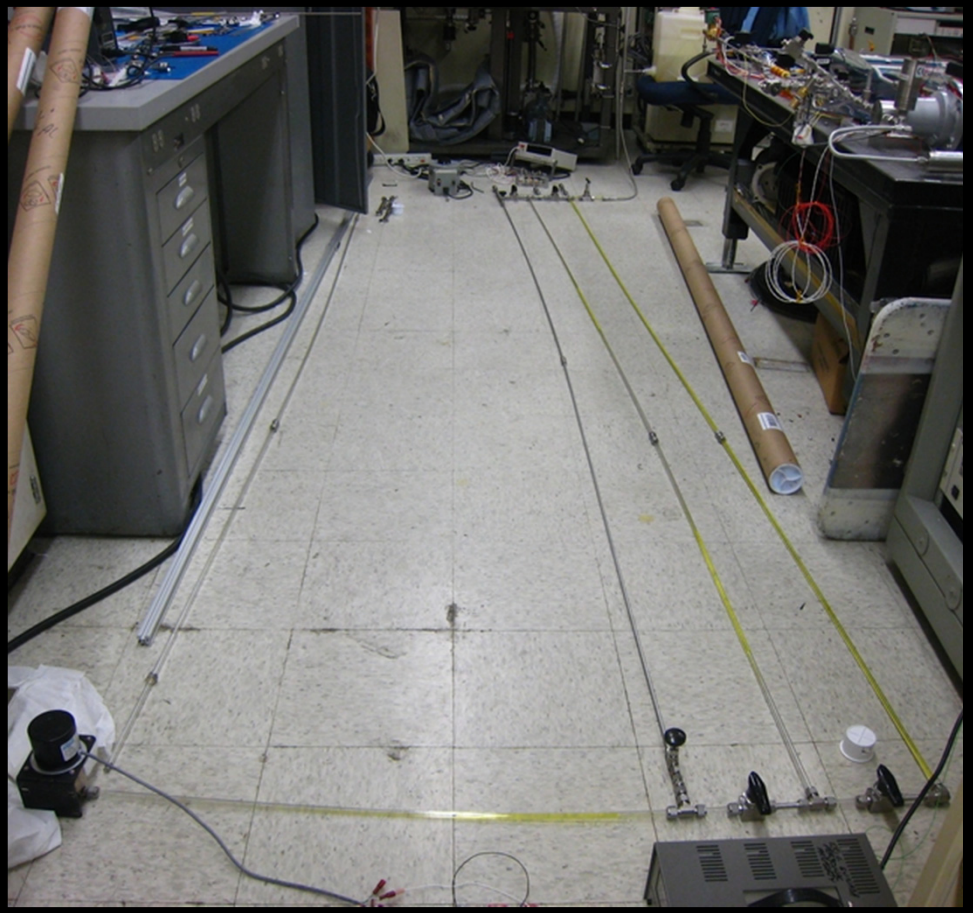


- Successful evacuation in 45s with 35W heater power.
- Works w/ favorable and adverse gravity

Video: single tube 12ft heater evac-cut.wmv

Multiple Tube Evacuation

- Evacuation of three tubes with individual heaters demonstrated successfully.
- ~15% of fluid remains in each tube due to adhesion to walls.



Incomplete Evacuation

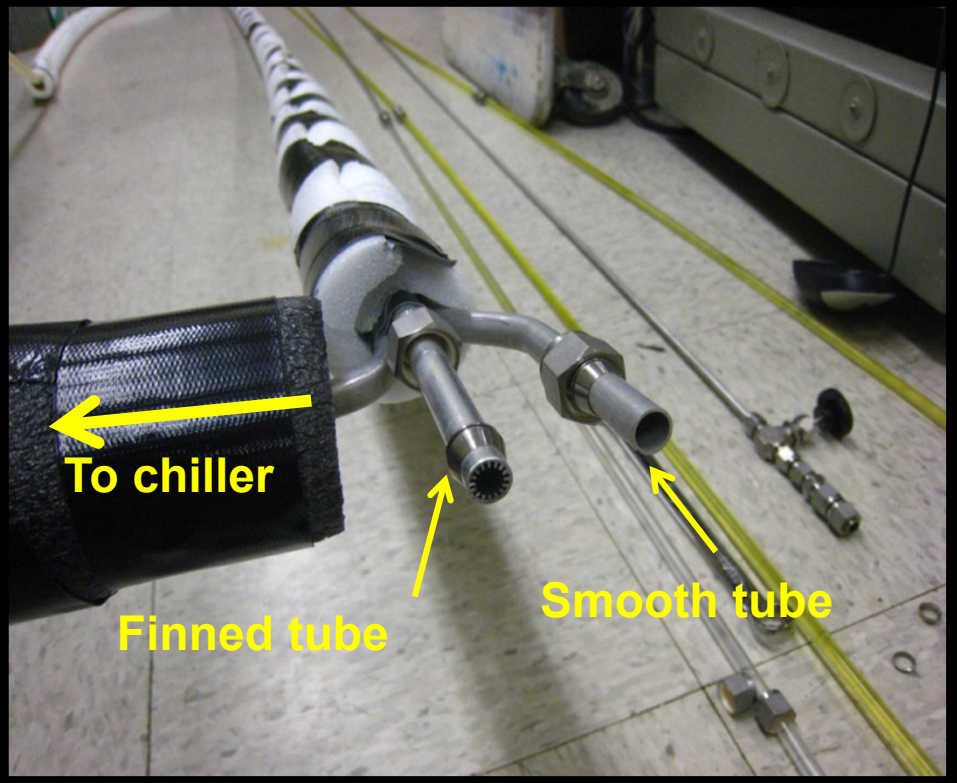
- 15% of fluid remains in tube as film on walls due to surface tension for all techniques.
  - Occurs for polycarbonate, teflon, Al tubes
- This fluid coalesces into “clots” to block flow upon freezing
- Use internally finned tubes to combat

Internally Finned Tubing

- Tube with internal fins to trap excess fluid by capillary action.

Internally Finned Tubing Experiment

- Smooth and finned tubes attached to chiller line to freeze remaining fluid
- Post freeze flow test to indicate blockage
  - Finned tube flows
  - Smooth tube – no flow



Summary

- Coolant freezing behavior not well defined
- Evacuation of stagnant fluid necessary
- Stub heater evacuation method is promising
- Internally finned tubes prevent blockage

Supplementary

- The following slides are for back-up QA purposes

Test results

- 50/50 PPG/H_2O mix behaves according to literature
- Liquid becomes opaque and highly viscous at ~ -30C (bulk T) and mag. stirrer fails.
- This is not a hard freeze, but essentially useless beyond this point (except for stag. Rad.)

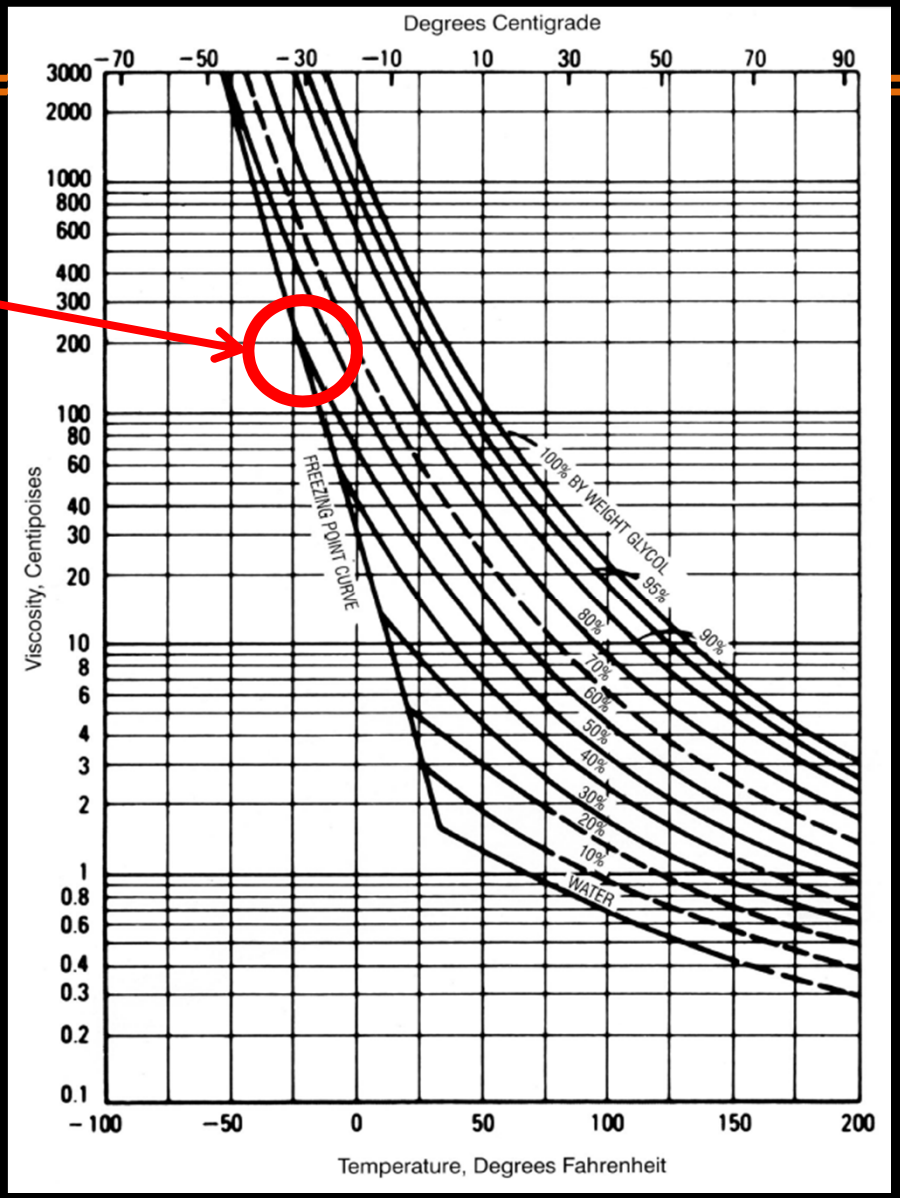
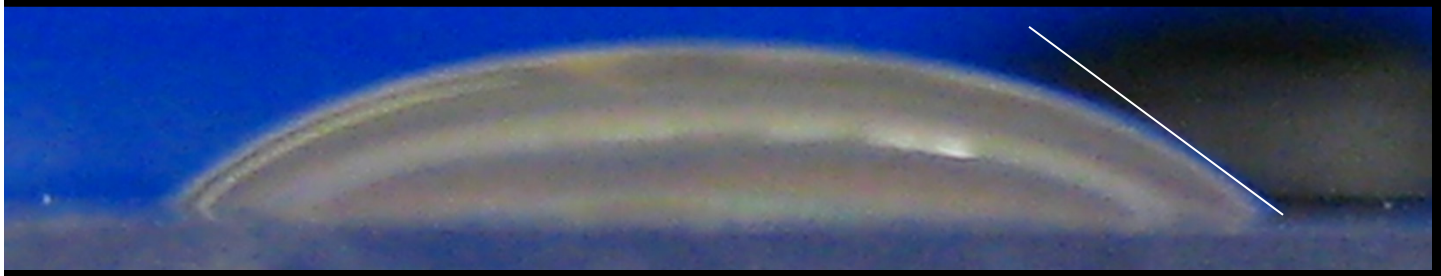


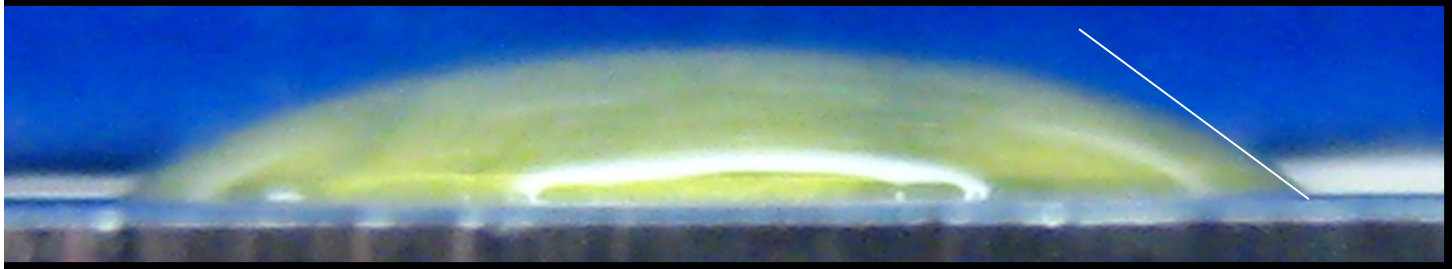
Fig 11 from "A Guide to Glycols" –Dow corporation, 2003

PPG surface tension/ drop angle test

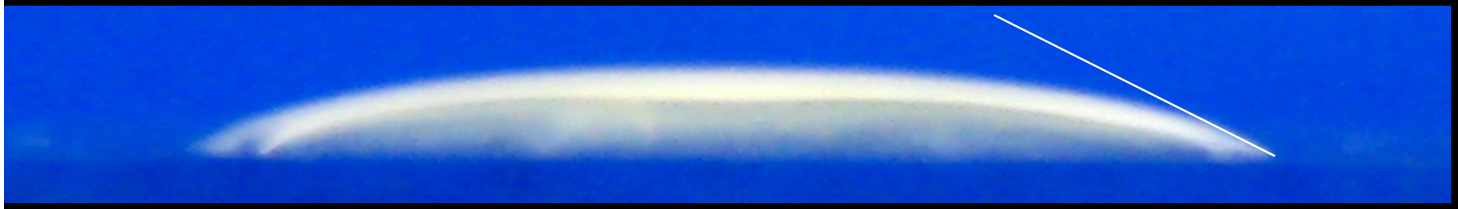
Teflon 42°



Polycarbonate 37°



Aluminum 36°



Glass 28°